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Types of classroom examples : "real-world" and traditional influences on learning solution chemistry

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Types of classroom examples:
"Real-world" and traditional influences on learning solution chemistry

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Abstract

Increasing connections between the real-world and chemistry is often thought to be a means of improving student learning of chemistry content. However, research in this area is limited and often qualitative in nature. This quasi-experimental study focused on the examples used during instruction in a high school chemistry unit on solutions. In contrast to what might be expected, students who experienced traditional chemistry examples outperformed those students who experienced "real-world" examples on a quiz. However, both groups performed equally on an exam involving the same concepts on the quiz and some other solution material given later in the unit. Explanation of these varied results leads back to the individual classroom and suggest that everyday examples alone are not enough to impact student performance.

Chapter 1

Introduction

Rationale for Study

Chemistry embodies many concepts and topics where the unobservable behavior of atoms, ions, or molecules is responsible for the observable behavior of a larger piece, or pieces, of matter. Chemistry also employs a unique vocabulary and symbolic language that is used to represent observable and unobservable particles. These three areas, unobservable, observable, and symbolic, come together to create rich understandings about the matter that makes up the world in which we live.

At the level of the secondary student in chemistry, these three areas create a vastly interconnected set of concepts, skills, and content to be learned. It can be argued chemistry is best understood by linking together the unobservable, observable, and symbolic, which leads to the purpose for this study. Gabel (1993) used a high school chemistry classroom to study the effect of using instruction focused on the unobservable particles that make up matter. Gabel found students in the treatment group displayed higher achievement not only on the particulate level, but also on the symbolic and observable level. These results demonstrate a very realistic situation where emphasis on particles cannot be achieved in isolation from the observable or symbolic nature of chemistry (Gabel, 1993). That is, atoms, ions and molecules cannot be separated from the behavior they cause nor from the symbols used to represent them.

A note of concern, however, was that all students in Gabel's study had relatively low scores on the chemistry concepts, skills, and content studied. One explanation offered for the low scores was that the chemistry concepts under study were not related to experiences students faced in their daily lives. As noted by Gabel, "Perhaps emphasizing the three levels of chemistry to describe common, everyday phenomena to which students could relate would make the instruction more effective" (1993, p. 194). The other explanation was that there was so much content included in the course the students could not learn it all. The first explanation seemed to offer a direct way to influence learning of chemistry within the confines of the traditional high school classroom. This study will explore the plausibility of using experiences students face in their everyday lives, or "real-world" examples, in addition to chemistry instruction focusing on particles, observations, and representation.

Research Question

The research question to be answered is: Will emphasis on the particulate nature of matter supported by "real-world" examples and phenomena have an influence on student understanding of solution chemistry?

Hypothesis, H: Chemistry students who receive instruction in particulate nature of matter accompanied by "real-world" examples during a unit on solution chemistry will have higher scores on a quiz and exam than chemistry students who receive instruction in particulate nature of matter accompanied by traditional examples.

Null Hypothesis, H_0: There will be no difference in the scores on a quiz and exam between chemistry students who receive instruction in particulate nature of matter accompanied by "real-world" examples and chemistry students who receive instruction in particulate nature of matter accompanied by traditional examples during a unit on solution chemistry.

Organization of the Study

The participants in this quasi-experimental study were high school students in a first year chemistry course. All students involved in the study received continued explicit instruction with respect to the particulate nature of matter during a unit on solution chemistry. All students had instruction and practice in connecting the unobservable, observable, and symbolic parts of chemistry. The treatment group was given laboratory materials, classroom examples, and demonstrations focusing on solution chemistry that they could find in their daily lives, and as such would be considered "real-world". The control group was given laboratory materials, classroom examples, and demonstrations based on more traditional chemistry material.

Both groups had an equal amount of total instruction time with the different emphases noted above. The study is post-test only where assessment of differences between control and treatment groups involved a quiz given during the unit instruction and an exam including solution chemistry given within two weeks of completion of instruction. An independent samples t-test and a nonparametric Mann-Whitney U test were used to analyze statistical differences and similarities between treatment and control groups on these assessments . The statistical results were then used to answer the research question and support or reject the hypotheses of the study.

Answering the Question and Beyond

The answer to the initial research question of whether or not "real-world" examples will influence learning when coupled with particulate nature of matter instruction, was not as clear as might be expected. A close look at the observations of the teacher-researcher, motivation of the students, and the sequence of the unit of instruction was required to explain the results of the study for the classroom in question. Several suggestions for future research are offered that could not only support the findings of this study, but could also have implications for instruction in many different chemistry classrooms. A "real-world" curriculum in chemistry may find its roots in such research.

Chapter 2

Review of the Literature

Particulate Nature of Matter

Central to the understanding of chemistry is the use of the particulate nature of matter to represent the macroscopic world (Calyk, Ayas & Ebenezer, 2005; Ebenezer & Erickson, 1996; Gabel, Samuel, & Hunn, 1987; Williamson & Abraham, 1995). The particles responsible for chemical phenomena are the atoms, ions, and molecules that comprise matter at its most basic level, and the particulate nature of matter is the observable behavior that is explained by these un-observable particles. That is, what we see can be accounted for by the attraction, motion, and rearrangement of particles we can not see (Nakhleh & Samarapungavan, 1999). Chemists, educators, and students may be more familiar with the kinetic molecular theory, which explains phenomena in terms of the atoms and molecules that make up matter, including dissolving, phase changes, and states of matter (Nakhleh & Samarapungavan, 1999). Most chemistry textbooks reference the kinetic molecular theory, especially with respect to gases and gas laws. However, most of the literature in chemical education refers to the same ideas under the heading of particulate nature of matter. The particulate nature of matter involves explaining observable events with submicroscopic particles (Kabapinar, Leach, & Scott, 2004).

The particulate nature of matter is usually formally introduced to students at the secondary level (Haidar & Abraham, 1991), although some success has been found using concrete examples with students in earlier grades (Skamp, 1999). Chemistry vocabulary supports inclusion of the particulate nature of matter in the curriculum, although care must be taken to specify "particles" as those exceptionally tiny bits of matter we can not see, meaning atoms, ions, or molecules. Instruction must focus on the correct terminology, where appropriate, as students might use the term "particle" to refer to something they can see, rather than to submicroscopic particles (Ebenezer & Erickson, 1996; Longden et al., 1991). Nakleh proposes a solution to misconceptions about particle terminology, "Therefore, educators should help students begin to understand the differences between atoms, molecules, and ions" (1992, p. 195). Care must be taken to differentiate particles that are on the microscopic level from those that are tangible.

Although poor understanding of particles is most likely related to lack of instruction in the particulate nature of matter (Gabel et al., 1989), there are problems associated with including this type of instruction at the secondary level. One problem is that students tend to attach observable properties to microscopic particles (Ebenezer & Erickson, 1996; Haidar & Abraham, 1991; Kokkotas & Vlachos, 1998). For instance, students might incorrectly describe matter at a high temperature as having hot particles, because "hot" can accurately describe a group of particles as a measure of their average kinetic energy, but "hot" cannot describe an individual particle. Students also tend to hold on to the notion that matter is continuous and accept the particle model only in limited contexts (Kokkotas & Vlachos, 1998). Another problem stems from teaching about particles before students are familiar with the observable properties that they encounter every day (Gabel, 1989). Without an understanding of what they see, particles are too much of an abstraction. Finally, as with any educational endeavor, students may just not understand the particulate nature of matter (Treagustet, Chittleborough, & Mamiala., 2003). Unfortunately, students who do not understand particle behavior are not likely to understand many topics in chemistry (Nakleh, 1992).

Johnstone's Triangle of Understanding Chemistry

To help make particles better understood we can connect the particulate view to both the observable and symbolic world of chemistry. Johnstone (1993) describes three areas, macroscopic, submicroscopic, and symbolic, aimed at understanding chemistry, as shown is Figure 1. Those in the chemistry field move between these three areas easily and are able to combine macroscopic, symbolic, and submicroscopic into fluid explanations (Johnstone, 1993). However, to introductory students of chemistry this is not the case. Understanding each level is difficult, regardless of trying to use all three concepts at once. As Johnstone points out, "The interior of the triangle is about as real to most people as a 'black hole'" (1993, p. 703).

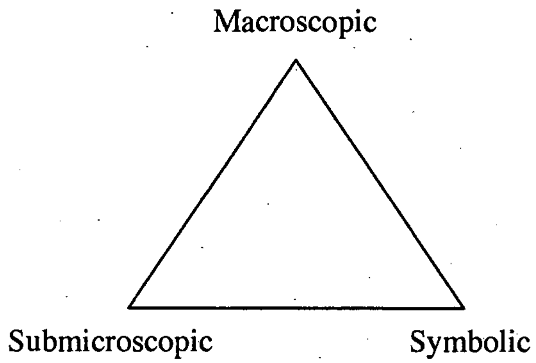

Figure 1. Johnstone's triangle of understanding chemistry.

This model, however, can be very useful in making connections between what students see, how students represent what they see, and the particulate nature of matter that explains both the tangible and the representational. According to Haidar and Abraham (1991), students see chemistry happening at the macro level while they are expected to explain what they see at the micro level. To create connections between these areas, teachers must ask for particle representations and actively promote connections between the explanation and observation (Haidar & Abraham, 1991; Treagust et al., 2003). To explain what is happening with particles, students must be able to use submicroscopic and symbolic levels of understanding at the same time, as student learning stems from the transfer of information between the corners of the triangle (Treagust et al., 2003). Treagust et al. (2003) summarize very well that for students to explain what is seen, they must rely on both the particulate view and the symbolic world of chemistry.

Particulate Nature of Matter and Conceptual Understanding

Emphasis on particle behavior will improve students' understanding of concepts involving the particulate nature of matter (Williamson & Abraham, 1995). Gabel (1993) studied the effect of using explicit particulate nature of matter instruction in high school chemistry classrooms. This instruction included worksheets and overheads that portrayed the particulate nature of matter and related particles to observations and chemical symbols. Gabel found that students who had the particulate instruction were better able to understand how particles, symbols, and observations are connected in chemistry. Students in the treatment group displayed higher achievement not only on the particulate level, but also on the symbolic and macroscopic level. Gabel suggests the student success in her study is a result of the interconnectedness of particles to the macroscopic and symbolic aspects of chemistry; particles can not be taught nor learned in isolation from the other two areas.

The abstract nature of chemistry requires understanding of particles. As Williamson and Abraham note, "The ultimate goal of increasing the understanding of concepts involving the particulate nature of matter is served by improving the way students visualize particle behavior" (1995, p. 522). They found that lack of student understanding may be the result of student failure to include particles in their mental models. Noh and Scharmann (1997) found that students were able to create more scientifically correct conceptions when they used pictures of particles than those students who did not use pictures. Harrison and Treagust (2000) argue that teachers and students should take class time to discuss and evaluate models of particles to improve understanding. Gabel concludes, "...[I]nstruction on the particulate nature of matter is effective in helping students make connections between the three levels on which chemistry can be both taught and understood" (1993, p.194).

Relevance and the "Real-World"

Learning is often compartmentalized by students into two categories: the information they learn at school and the information they learn in their "real" lives (Gabel, 1993; Longden et al.,1991). Connecting these two areas is often thought to be key to student learning. Longden et al. (1991) used the concept of dissolving to study the relationship between school knowledge and everyday knowledge. They found, surprisingly, that there were more pupils with the correct particulate view of dissolving than with the correct everyday view of dissolving. Compartmentalization still existed with the students and more knew the correct "school" answer. They suggest that if science teaching is to be more successful in everyday areas, then instruction must use class lessons to address everyday language directly (Longden et al., 1991). Their work implies that compartmentalization will continue unless effort is made on the part of the instructor or curriculum to connect "real world" experience with school knowledge.

Williamson et al. (2004) reported that students tended to respond to questions in either everyday terms or particulate terms depending on the structure of the question. Any time scientific wording was used in a question, students were likely to respond to the question using scientific terminology. Even if very few particulate terms were used in the question, students still answered scientifically, although this did not guarantee their answers were correct. The study does suggest that integration of everyday and scientific thought can be applied to link microscopic and macroscopic explanations and help decompartmentalize the learning of chemistry (Williamson et al., 2004).

This leads to the idea of a relevant curriculum. Again, the notion is that students will better learn if the information they are learning is relevant to their lives. However, as Wink (2005) points out there are several components to be considered when trying to make concepts relevant, including: the particular student, the mediator, the materials, and assessment. Ideally, he argues, relevancy will be found using a model of teaching content within a relevant context. Ebenezer and Erickson (1996) add that teachers need to realize the ideas their students have are very closely related to the phenomena or contexts being used in the classroom and students are quite likely to have different interpretations of the same event. "The chemistry classroom should emphasize contextual learning – enabling students to know where everyday conceptions of chemical phenomenon are appropriate and where conceptions from the community of chemists are more appropriate" (Calyk et al., 2005, p. 46). The link between content and "real world" must be created and emphasized in the classroom.

Literature on changes to make curriculum relevant to the chemistry student is sparse, but recent. Duprey and Sell (2003) designed group learning activities for undergraduate students centered around real world settings. They found their greatest success with a unit on fragrances. Students were very excited and enjoyed making and marketing their own fragrances for certain household needs. However, they reported that these activities may or may not have any influence on improved learning of chemistry. Miller et al. (2004) evaluated undergraduate student attitudes toward using various types of instrumentation in the laboratory setting. Students felt that these lessons allowed them to develop skills that would be valuable to them in the future. Both of these studies tried to link chemistry to the roles of professional chemists, which certainly is "real world" for undergraduate studies in chemistry, but may not lend itself to application in a high school classroom.

"Real world" experiences for high school students must have a broader scope and truly include phenomena they will encounter in their daily lives. Chen and Yaung (2002) offer a laboratory experiment that can be used at the secondary level. The experiment involves the stoichiometry of Alka Seltzer ® and vinegar, two products that can be found in the everyday world. It was found that students enjoyed the experiment as compared to their more traditional laboratory activities and wanted to do more experiments like it. Other studies focusing on secondary chemistry were nowhere to be found and none of the three studies mentioned above focused on improved student learning with respect to everyday examples. Instead, the feedback from students was mainly qualitative; students felt good about the real-world connections.

Student motivation can also play a part in how students perceive "real-world" instruction as well as how much they might learn. Motivation is guided by student commitment to a learning goal and student effort toward that goal (Clark, 1997). If students are initially committed to learning then they will put forth the effort required to learn. Using "real-world" experiences could improve the commitment and effort students display toward their learning as the experience may seem familiar or serve as a direct application of what they are learning. Motivation toward "real-world" applications can lead to greater student success and learning.

Summary

To conclude, the particulate nature of matter is requisite to the learning of chemistry, but ideas of particles can not stand alone. Connecting observable events, symbolism used in chemistry, and the particles that are unseen forms a strong basis for understanding chemistry content. The Science Education Standards (National Research Council, 1996) state that content is fundamental if it represents a central idea and has explanatory power. The Standards also state that content is essential if it applies to everyday experiences, an area where more research is needed.

Chapter 3

Materials and Methods

Description of Course and Potential Participants

The chemistry course used in the study was an introductory inorganic chemistry course taught in the only high school in a mid-sized city in the Midwest region of the United States. The following topics were covered during the year: chemical and physical change, chemical reactions and equations, stoichiometry, atomic structure, bonding, solutions, acid and bases, and kinetics. It is recognized as college preparatory and is the capstone of four curricular areas offered in the school, preceded by earth science, biology, and physics. The chemistry course met six class periods per five day week. One day of the week the students had a "double lab" period where they met for two periods in a row to allow more time for laboratory instruction. There were two main types of instructor designed assessments, quizzes and exams. Exams were given at the midterm of each quarter and the end of the first and third quarter, totaling three exams per semester. There were at least two quizzes given each quarter, in-between exams.

The sample group of students was selected from five sections of the chemistry course described above, taught by the teacher-researcher. The vast majority of students were seniors, ranging in age from 17-18, and had taken at least two years of science at the school prior to enrolling in chemistry. An informal survey given by the teacher-researcher at the beginning of the second semester found that the majority of students saw themselves in a post-secondary institution the following year. When asked in this same survey why they had chosen to take chemistry, many interpreted the question as to why they had chosen to take

Chemistry instead of Honors Chemistry or Principles of Chemistry, the two other chemistry courses at the school. This implies that it was an automatic choice to take chemistry as a course their senior year; the only choice they had was which of the three different chemistry courses they would take.

The day of the week each class had their double lab period dictated the control versus treatment groups. The two classes that met for two periods on Mondays were deemed the control group and the three classes that met for two periods on Tuesdays were selected as the treatment group. This allowed for ease in altering materials used in the laboratory sessions as well as planning the various lessons. Since the class sections were pre-established by a master school schedule, it was necessary to determine if the non-randomly formed groups were statistically academically different before the study was conducted. The first semester final exam, consisting of 80 multiple choice and two problem solving questions, was used to compare the groups. An independent samples t-test using the exam scores found a mean of 73.4 and standard deviation of 8.27 for the control group of 39 students and a mean of 70.4 and standard deviation of 10.9 for the treatment group of 54 students, resulting in a t value of 1.42. The test found a two-tailed significance of 0.160 at the $p = 0.05$ level, establishing that there was no significant difference between the two groups. This result was taken as sufficient evidence that the academic ability of the control and treatment groups was equal at the start of the study.

Instruction

Particulate instruction was used during the first and into the second semester with both the treatment and control groups. This type of instruction included visualizing and drawing pictures of particles, atoms, ions, and molecules, while learning phase changes, chemical equations, and bonding, among other topics. Particle explanations of phenomenon were shared with students, where appropriate, and they were expected to consider chemistry in terms of particles. The particulate instruction also included connections to Johnstone's (1993) triangle of understanding chemistry. Students spent class time connecting the observable, symbolic, and sub-microscopic strands of many chemistry concepts from the beginning of the year through the study and beyond. For example, when considering salt dissolving, at the observational level students would see the salt disappear when placed in water. One way this observation can be symbolically described is by writing NaCl (aq). At the particulate level, students would explain dissolving by describing the water molecules actively pulling apart the crystal lattice of salt due to attractive forces between the water molecules and salt ions. Explicit connection is made between these three levels of chemistry during class time, as well as through various assignments.

A variety of teaching strategies and classroom activities were used during the course of the unit. Most of the class time could be described as guided inquiry or discussion based, where the students were expected to actively participate in their own learning. The timeline of the unit can be found in Table 1.

Table 1. Timeline of instruction for the solution unit.

Day 1	Activity: What is a Solution? Students classify 13 different examples as a "solution" or "not a solution." Then they discuss in small groups the characteristic observable properties of solutions. Finally, the instructor organizes a culminating discussion about properties of solutions.
Day 2	LAB: Solubility Curves. Students collect data on potassium chloride and ammonium chloride solubility at different temperatures. The lab groups compile data to create graphical solubility curves.
Day 3	LAB: Solubility Curves (cont.). The lab groups compile data to create graphical solubility curves.
Day 4	Instructor lead discussion: Unsaturated, Saturated, and Supersaturated solutions. Examples used to generate questions for students to answer in small groups and share with the whole class.
Day 5	Instructor lead discussion: Interpreting solubility curves and gas solubility. Used an overhead transparency to allow student time for practice questions with the solubility curve.
Day 6	Instructor lecture: Solution concentration. Introduced students to different units of concentration, such as percent by volume and molality. Showed examples of bottles or packages with different concentrations.
Day 7	LAB: Conductivity Titration. Students titrate barium hydroxide with sulfuric acid while monitoring the conductivity of the solution.
Day 8	Instructor lead problem solving day: Dilution problems. Students learned how to calculate concentrations of solutions that have been diluted.
Day 9	Demonstration: Density and Floating. Students observe and manipulate an aquarium with four solutions, two of which are sinking and two floating (i.e. cans of diet pop and cans of regular pop). Students are asked to write an explanation for what they see both on the observational level and at the particulate level.
Day 10	Instructor lead discussion: Colligative properties. Students were initially asked what happens to a beaker of ice water when a solute is added. The instructor followed up with information on changes in solution vapor pressure, freezing point, and boiling point. Graphical examples were given.
Day 11	LAB: A Study of Freezing Point. Students used antifreeze or ethylene glycol to measure the difference in temperature of pure ice water or ice water with the solute. Each lab group was assigned a different combination of ice and solvent. Groups shared data and compiled into a graph.
Day 12	Instructor lead problem solving day: Colligative property calculations. The instructor modeled then allowed student practice time for colligative property problems.
Day 13	QUIZ: Solutions. The quiz included material studied on days 1 – 7.

Solution chemistry was chosen for the topic of the study because there were many possibilities for using everyday or "real-world" examples in contrast with more traditional examples. The control group, n=39, was given traditional chemistry examples with respect to the concepts under study while the treatment group, n=54, was given everyday examples. An example of the difference is as follows: when discussing unsaturated and saturated solutions in class, the control group examples included sodium chloride and potassium nitrate solutions, labeled with their concentration in common laboratory glassware, while the treatment group saw sugar in water and the creation of homemade syrup. Appendix B contains a complete list of the objectives, information on particulate instruction, and the examples used for both control and treatment groups. Both groups had the same amount of total time in each topic area, the same number of laboratory activities, demonstrations, and homework assignments, and the same number of assessments. In short, every aspect of instruction was identical for both groups except the types of examples they were given to illustrate the solution concepts.

With respect to types of examples, using something that is "real-world" may automatically lead to the concept of relevancy. For this study, "real-world" is meant to imply something that a student could see outside of the chemistry classroom. The "real-world" example may be found in the grocery store or on the shelf in the garage or even elsewhere in the school. For example, salt water could be seen by a student at the beach or at home as a solution with which to gargle a sore throat. But 0.1 M NaCl solution will only be found in a chemistry classroom. Both are salt water, but the context within which they are found is different and as such, students may attach different meaning to each, as accorded by constructivist learning theory. Relevancy is described by Wink (2005) as curriculum that will cause a dramatic change in student behavior because the students have a personal link to the lesson. This link will improve student learning of content. As used in this study, "real-world" is different than "relevant." Adding relevancy to the examples can be very difficult as students will attach their own meaning to the examples, what might be relevant for one students is not so relevant to another.

Assessment

Assessment in the study involved both a quiz over solutions and the third quarter exam given during the chemistry course. Both assessments reflected the pre-determined objectives for the solutions unit and the types of questions used included multiple choice, free response, and quantitative problem solving. The content of the questions was placed into one of the following three categories, or some combination of these categories: particulate, traditional, or "real-world". Particulate questions asked the student to reflect on the part a matter that is unseen, the particles that are responsible for behavior that can be seen. Traditional questions focused on typical chemistry content and could easily be found in any chemistry textbook. The "real-world" questions referred students to experiences they may have had or materials found beyond the walls of their chemistry classroom. The scores of the solutions quiz and third quarter exam were used to answer the research question.

The solutions quiz was given toward the end of the unit, while the students were still studying solution chemistry. The quiz consisted of five free response questions based on the first five objectives listed in Appendix B. There were two questions that explicitly referred to particles, questions one and four, that can be found in the quiz in Appendix C. Question one used pictures of six beakers, each with varying number of solute particles or solvent, to ask about concentration comparisons between the solutions. Question four asked students to fill in two beakers to illustrate the difference between solubility of a gas in hot or cold water. Question three on the quiz asked about an everyday application of solutions using Kool-Aid ® and question five was very traditional, asking students to rank four solutions of varying molarity and concentration in order of increasing conductivity. Question three could be classified under two different headings, either particulate or traditional depending up on how the student chose to describe what happens when an ionic solute is placed in water. The quiz was administered during a regular class period and a maximum of 25 minutes was allowed for completion. The quiz was scored by the teacher-researcher using the pre-determined scoring key found in Appendix C. Students could earn from zero to the maximum points possible on any question.

The third quarter exam was given a week after the conclusion of the solution unit. This exam also included some questions about bonding and equilibrium, topics that extended beyond the solutions unit but were part of the third quarter of the course. The exam, found in Appendix C, began with 20 multiple-choice questions, 13 of which were about solutions. The majority of the multiple choice questions would be considered traditional in nature, although a few did ask about particles, such as question eight, which asked about the number of ions per liter of solution and number twelve, which asked about the relationship between ions and conductivity. None of the multiple choice referenced any real-life situation. The multiple choice was scored with each question being worth one point and students earning either zero or one on each item. Of the six free-response questions on the exam, five focused on solutions. Question 21 was a "real-world" question asking about why antifreeze would be a useful additive to the water in car radiators in both the winter and summer. Question 22 was a particle question asking students to draw five water soluble molecules as they might look dissolved in a beaker of water. Students were asked to briefly explain their drawings. The next section of the exam involved four questions which students were asked to answer with little or no explanation. Question 23 was very traditional as it asked for the freezing point of an aqueous solution of magnesium sulfate. Students would need to use the equation for freezing point depression, as well as calculate molality from the information given. The answer was strictly numerical. Question 24 was a dilution problem that also asked for a drawing of the new solution. This question could be considered both traditional and particle in nature. The mathematical reasoning would make it traditional but the picture asked for a particle representation. Question 26 had five sub-parts that asked about a given solubility curve. The parts were both qualitative, asking about type of saturation, and quantitative, asking about the amount of solute that could be dissolved. The scoring key found in Appendix C illustrates how points were awarded on each of the open-ended questions by the teacher-researcher. The exam was administered during a regular class period and a maximum of 45 minutes was allowed for completion.

Sample Participation

The study was described to potential participants during class at the end of the same week the scores for third quarter exam had been returned to them. An informational letter and consent form were handed out at this time as well. These documents are included in Appendix A. The students were told that all of the instruction and assessment with respect to the study had already been completed and there was no further expectation of them. The request was to use their scores for data analysis. Students were encouraged to ask questions about the study and their participation in the study. They were given a week to return the consent form, which required both their signature and the signature of their parent or guardian. The sample size was 93 out of a possible 98 students.

Limitations of the Study

Potential limitations of the study include non-random selection of the control and treatment groups. As mentioned earlier, the t-test results using the subjects' score on their first semester final exam suggested that there was no statistical academic difference between the groups prior to the study. This analysis increases confidence in the study results with respect to generalization because the original groups were not found to be different in a significant way.

With respect to reactive effects, since the students were asked for permission to use their data after the differentiated instruction was applied to the groups and after the assessments were administered, the potential influence of realizing they were part of a study should be minimal. There was no awareness at the time of instruction or assessment that the students' scores would be used for anything other than their normal grade.

It is thought treatment diffusion effects were minimal as well since the only difference in content were the examples to which the students were exposed. Both groups experienced the same type of instruction, the same activities, and the same assessments. It is possible that students spoke of their experiences and recognized differences, however, the teacher-researcher did not note any overt consciousness on the part of the students to this end.

Threats to internal validity are decreased as the study did not include a pretest that could influence posttest scores and the timeframe of the treatment was short. The unit lasted three weeks. Finally, the small sample size and the fact that the study focused on a chemistry classroom and the topic of solutions can limit the ability to apply the conclusions toward other courses, including other science courses.

Chapter 4

Results and Discussion

Introduction

The early part of this paper outlines the rationale for including particulate nature of matter instruction in chemistry courses as well as the question of using "real-world" examples within chemistry instruction. The study was designed to answer the question: Will emphasis on the particulate nature of matter supported by real world examples and phenomena have an influence on student understanding of solution chemistry? An examination of the results leads to a potentially conflicting answer to this question.

Statistical Results

An independent samples t-test comparing groups and overall scores on the solutions quiz and third quarter exam was performed using SPSS. Analysis of the quiz scores shows that the control group significantly outperformed the treatment group on the overall quiz score. As reported in Table 2, alpha is significant at the .05 level (2-tailed) for the solutions quiz with assumption of equal variances between the two groups, which allows for the conclusion of a significant difference in performance between the two groups on the solutions quiz. However, analysis of the third quarter exam finds there to be no statistically significant difference in overall scores. With respect to the exam, the Levene's F test of equality of varience was violated, therefore, the SPSS output reported is that where equal variances are not assumed and no difference in scores was found at alpha equal to .05.

Table 2. Independent samples t-test comparing groups and overall score on quiz and exam.

Assessment		N	x	sd	t	*p*
Solutions Quiz (Maximum score = 21)						
	Control	39	16.08	2.78	3.01	.003*
	Treatment	54	14.19	3.14		
Third Quarter Exam[1] (Maximum score = 50)						
	Control	39	41.23	3.39	1.84	.069
	Treatment	54	39.57	5.27		

* statistically significant at alpha = .05 (2-tailed)
[1]Levene's test of equality of variances is violated on these variables.

A non-parametric Mann-Whitney U test was also used to compare groups and overall scores on the solutions quiz and third quarter exam. This test is more conservative than the t-test and established the same result. The control group significantly outperformed the treatment group on the quiz where alpha is equal to .05 (2-tailed), while there was no significant difference in the overall third quarter exam scores between the two groups. The results of this test can be found in Table 3.

Table 3. Non-parametric Mann-Whitney U test comparing groups and overall score on quiz and exam.

Assessment		N	z	*p*
Solutions Quiz (Maximum score = 21)				
	Control	39	-2.67	.008*
	Treatment	54		
Third Quarter Exam (Maximum score = 50)				
	Control	39	-1.24	.216
	Treatment	54		

* statistically significant at alpha = .05 (2-tailed)

What Happened with the Hypotheses?

Hypothesis, H: Chemistry students who receive instruction in particulate nature of matter accompanied by "real-world" examples during a unit on solution chemistry will have higher scores on a quiz and exam than chemistry students who receive instruction in particulate nature of matter accompanied by traditional examples.

Null Hypothesis, H_0: There will be no difference in the scores on a quiz and exam between chemistry students who receive instruction in particulate nature of matter accompanied by "real-world" examples and chemistry students who receive instruction in particulate nature of matter accompanied by traditional examples during a unit on solution chemistry.

With respect to the hypotheses and the overall quiz scores, the significant result of both statistical tests would lead to rejection of both the hypothesis and the null hypothesis.

That is, there *was* a significant difference in the quiz scores between the control and treatment groups and the difference favored the students who had traditional instruction, not the students who had "real-world" instruction.

However, the result of the analysis of the overall scores on the third quarter exam suggests rejection of the hypothesis and support of the null hypothesis. Or, there really is *no* difference between the two groups with respect to the types of examples they experience, "real-world" or traditional, as measured by that assessment.

The Results and Other Research Studies

The absence of a difference in scores between the two groups on the third quarter exam supports the idea of compartmentalization as described by Longden et al. (1991) by suggesting that only using everyday examples in instruction was not enough to make the connection needed between the "real-world" and what happens in the chemistry classroom. It would seem as well, that the enhanced score by the control group on the quiz speaks to the result Longden et al. (1991) found in their own study, where students had the correct school answer to describe dissolving, but not the correct everyday view of dissolving. Students in the current study compartmentalized such that the control group learned the traditional chemistry content being presented, but the treatment group did not attend to the content because they saw "real-world" examples that did not fit with the information they were learning in school. The suggestion made by the prior study still rings true: compartmentalization will continue unless effort is made on the part of the instructor or curriculum to connect real world experience with school knowledge. The current study carries the suggestion even further in that effort on the part of the instructor and students in the classroom must reach beyond only using "real-world" examples. Time must be taken to let the novelty of common experiences wear off so that the application of the experience to the chemistry concept can be made successfully.

Duprey and Sell (2003) reported that their students enjoyed the time spent on activities that were based on applications of chemistry careers. They also reported that they were unsure if their work had improved how their students learned the chemistry content. In response, the current study would point out that "real-world" examples do not improve student learning of chemistry content. At best, the examples have no effect and at worst, the students that have been given "real-world" examples perform at a lower level on the same assessment.

The Results and the Current Study

Teacher-Researcher Observations

Observations made by the teacher-researcher, accompanied by the sequencing of the unit, and a link to student motivation may start to help explain the conflict in the analysis. Table 4 contains reflections made by the teacher-researcher from early in the solutions unit after both groups completed an activity designed to discuss characteristics of solutions. Both groups looked at examples of thirteen different substances and were asked to place each substance into the category of either "solution" or "not a solution." The specific examples for each group can be found in Appendix B. The variance in student conversation between the two groups was striking during the time of the activity (and prompted the teacher-researcher to record her reflections). The treatment group had very casual conversations, such as whether or not they liked that kind of pop or if they had ever tried this particular substance. All in the treatment group were confident that milk was a solution (even though it is not) and their discussion of milk quickly focused on what kind of milk they liked to drink. The treatment group was familiar with the substances (which was the point of choosing those substances) and their approach to the activity was very familiar as well.

In contrast, the control group treated the activity much more formally. Their conversations centered on recognizing the correct formula or symbol from the bottle label or using chemistry terminology to describe the substances. For this group, there were few substances that they all classified as either "solution" or "not a solution." Overall, the control group treated the activity as a more objective laboratory experience, and tried to use terminology and prior knowledge as appropriate.

Table 4. Teacher-researcher reflections on "What is a solution?" activity

Treatment Group	Control Group
Students were very interested in the flip over fun toys and the Orbitz ® soda. Much of their talk centered around very casual things: did they like pop, skim milk is gross or great, have you ever tried Orbitz ®? How old is it (The Orbitz ®)? And other such commentary. There was at least one mention in each class of the term precipitate with respect to solutions. There was almost unanimous agreement that milk was a solution…I used this example to point out that since we can't see through milk, it is not a solution. After this discussion, we spent time reclassifying several of the examples.	Student conversation centered around the labels used on their examples. Comments like: if it has molarity, it must be a solution, if it is called saturated, it must be a solution, or can a precipitate be seen? They were only interested in one example, the rheoscopic fluid. Many wanted to play and watch it for most of the class period, although very few classified it as a solution. The example that involved the most disagreement in these classes was the magnesium hydroxide. I used it in the same way I used the milk for the treatment group.

The rest of the first week of solution instruction included similar observations and contrasts between control and treatment groups. Using hot tap water as an example of gas solubility in water created discussion in the treatment group of making ice cubes and these students were also quite interested in the class demonstration of making syrup. In contrast, the control group saw bubbles in a beaker of water that had been warmed and saturated solutions of sodium chloride and potassium nitrate, very traditional examples which the study required. The treatment group was really interested in their examples and their discussion was quite lively during class time as they asked many "how" and "what if" questions, more so than observed of the control group.

Student Motivation

Motivation influences the amount of learning a student can experience. Clark (1997) describes motivation as a two stage process; in the first stage learners decide on their commitment to a learning goal, and in the second stage learners decide on the amount of effort they expend on learning goal. So, if the learner is not committed to learning because they already think they know the content, they will not put much effort into this learning. This could describe what happened with the treatment group: during the commitment phase they decided they already had enough knowledge of solutions and then during the effort phase, they did little work to learn about solutions.

Salomon (1984) found that learners tended to not master material presented in their preferred format because they put forth less effort than those who were learning in an unpreferred style. In a study designed to let students select their preferred learning style, he found those working in areas other than their preferred choice significantly outperformed students who could select their favorite mode of instruction. In light of this, and the observations described above, treatment group students may have performed at a lower level because they felt they were familiar with the solution information being presented and therefore spent less time, or less effort, learning the new material.

However entertained the treatment group may have been with their "real-world" focus, they may have missed the fact that they were learning something new and that they would be held accountable for this learning. Their familiarity with the substances being used and their interest in the examples shared in class may have made them overconfident in their knowledge of the solution content being taught. This failure to attend themselves to new chemistry information appears in their lower quiz scores because the quiz directly assessed the first part of the unit. It appears likely the control group did better on the quiz because they were focused on examples that were more formally oriented to chemistry and as such, these students were able to learn the new material without distraction.

Sequence of the Solutions Unit

How then, do the observations and connection to motivation explain the lack of a significant difference between the control and treatment groups on the third quarter exam? The answer to this question may be found in the sequence of the content in the solutions unit. The objectives for the unit, found in Appendix B, are listed in the order in which they were taught. The first three objectives were very qualitative in nature, lending themselves to "real-world" examples that were very tangible and lend themselves to student experience. It was during the time these objectives were taught that the previously described observations took place. The remainder of the objectives were either particulate or quantitative in nature making them very formally connected to the world of chemistry.

For instance, it can be argued that any time particles were used for explanations, the learning became more traditional because students were only formally introduced to describing observable events using particles at the beginning of the chemistry course. Regardless of the examples used, students were just not as familiar with particles as they were with syrup or ice cubes, so in light of motivation, students may have put more effort into understanding particles. Particles had also been a major focus during the course prior to the study, so students may have spent more time because of their prior experience with particles. Also, if students are asked scientific questions, they tend to respond scientifically (Williamson, et al., 2004).

Learning quantitative objectives can be explained in much the same way. When a mathematical formula came into play, the quantification required may require more effort on the part of the student to learn, or at least, mathematical problems look more traditional. Quantification may have also been easier because students were able to use the new formulas in a purely algorithmic manner. Much research in chemistry problem solving established that students can often solve problems algorithmically without really understanding what has happened chemically (Herron & Greenbowe, 1986; Nakhleh, 1992; Nurrenbern & Pickering, 1987; Smith & Metz, 1996). In either case, the type of example to which they were exposed, traditional or "real-world", made no difference because all students were using the mathematical formula in the same way. As a result, there was no significant difference between the two groups.

The sequence of objectives is connected to the quiz and third quarter exam assessments in the following way: the first five objectives were assessed by the quiz and all seven objectives were assessed by the exam. So, the quiz scores may have been significantly different because the questions on the quiz focused on the objectives and "real-world" examples with which the treatment students felt more comfortable and therefore the treatment students spent less effort learning the new material. The control students saw the quiz objectives as normal chemistry content to be learned and as such, outperformed the treatment group.

With respect to the third quarter exam, the objectives assessed by free response on the quiz were found on the exam in the form of multiple choice questions. Students who did poorly explaining an answer via free response on the quiz might have more luck choosing the correct answer from four possible choices on the exam. Also, students could use their quiz to study for the exam. This would give them time to re-learn the material and correct their mistakes. Another factor to consider is that the free response portion of the exam focused on those objectives that were either particulate or quantitative in nature. These more traditional objectives, as described above, may cause *all* students to spend more effort on learning and as such, no statistical difference was found between the groups. All of these ideas could help explain the lack of difference in the exam scores.

Summary of the Conflict

In conclusion, the conflicting results could be attributed to the lack of motivation of the treatment group to learn the "real-world" examples used for the early objectives which may have caused a difference on the overall quiz scores in favor of the control group. This difference disappears on the exam because the objectives become more formally connected to chemistry, the students had time to learn from their mistakes on the quiz, and the questions they may have missed on the quiz turned into multiple choice items on the exam.

Overall, the results strongly suggest that "real-world" examples alone were insufficient to exact a significant change in student learning of the solution unit material. Instead, the "real-world" examples must be placed in the context of the concept under study and connected to the terminology and problem solving aspects of this content. The instructor must take a very active role in making connections happen within the classroom, perhaps by using the "real-world" example as a starting point for a discussion or activity. This would serve to promote the example into the role of content to be learned. Then the former example takes a primary role and can be actively linked to and explained both symbolically and at the particulate level. "Real-world" examples as illustrations are not good enough in the classroom; instead the "real-world" connection must be developed into a significant learning experience.

The suggestions for "real-world" examples above could lead to a relevant curriculum; one that engages students on a personal level. What was studied is the extent of relevance, that is, did the students take the "real-world" examples as a behavior changing influence? It would seem, according to the assessment data, that the examples were not relevant to the students. However, the study did not measure the long-term influence the examples might have on the students. Over time, the "real-world" examples might end up as relevant learning.

Chapter 5

Conclusion and Suggestions for Further Research

Based on the outcome of this study, there are several areas where new research should focus. One area is to continue to study the original issue proposed by Gabel (1993) that was the driving force behind this work. She wondered if by making the content more relevant, students would learn more. The conflicting results of this study warrant a continued look at relevance in the chemistry classroom with respect to improving content knowledge in chemistry.

"Real-world" examples may lend themselves better to certain types of chemistry content than others. A future study could examine when "real-world" examples are most effective. A different study might examine the use of "real-world" applications with algorithmic problems versus open-ended problems that require explanation. This work could extend the research on algorithmic problem solving beyond mathematical problems to include areas with which students are more familiar.

The lack of effectiveness of "real-world" examples could be attributed to a lack of motivation on the part of the students. More research on motivation with respect to "real-world" examples would shed some light on the cause of creating relevant curriculum for students. Answering the question, "If students think they already know the content being taught, will they still put effort into learning this content?" would potentially support the findings in this study and provide a guide for using "real-world" applications in chemistry coursework.

Perhaps improving the influence of "real-world" examples is simply a matter of time spent with the application. Extra time could be useful to allow students to appreciate the novelty of the "real-world" examples used as well as connect the examples to the content in question. A future study might do well to look at increasing time spent with examples and "real-world" applications to decrease the novelty effect and potential distraction and increase student learning of the content. As Calyk et al. (2005) point out, the link between content and the "real-world" must be emphasized in the classroom.

Using "real-world" examples may be an instinct felt by many chemistry instructors as a way to help their students learn, however, this feeling is not necessarily supported by this particular study. More data needs to be collected to provide evidence that a relevant curriculum will enhance student learning in their chemistry classrooms.

Appendix A

Informed Consent Documentation

A.1: Letter to Students and Parents

March 2006

Dear Ames High Chemistry Student and Parent,

I am working toward completing a Master's Degree in Science Education at Iowa State University. The culmination of this degree involves collecting data concerning an aspect of our chemistry class, analyzing the data, and reporting the results in the form of a thesis.

Research concerning the particulate nature of matter in other chemistry classes has directed me to a part of our class I would like to study. As you are aware, three levels of understanding chemistry, microscopic, macroscopic and symbolic, have been a recurring theme in our study. I will be looking at how emphasizing particles influences your learning of chemistry concepts. Please know that no chemistry content will be compromised to complete the study. All homework, quizzes, tests, and classroom activities are designed to meet pre-determined learning objectives for the course.

In order to collect data, I need permission for you to participate in this study. Strictly speaking, this means I need your permission to use your assessment data (scores on homework, quizzes, exams, laboratory reports, etc.) for analysis. All of your scores will be kept confidential and at no time will you be identified as an individual. Your permission to participate in the project is voluntary and you may decline your permission at any time. If you do not want your data included in the study, you will still complete all the assignments because they are part of our course.

The results of the research in our classroom will be used to inform the greater scientific community as to the role of examples in learning high school chemistry. It is hoped that this research will lead to better teaching and learning of chemistry for our class and future classes.

I appreciate your support in helping to construct a better chemistry classroom as well as to complete the requirement for my advanced degree. Please see me with any questions you may have. Thanks! I look forward to a fantastic spring of chemistry.

Sincerely,

Aileen M. Sullivan
Your Chemistry Teacher

A.2 Informed Consent Document

Title of Study: The Particulate Nature of Matter and Chemical Phenomena
Investigators: Aileen M. Sullivan, B.A.
Joanne K. Olson, Ph.D

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION

The purpose of this study is to look at how instruction that includes the particulate nature of matter in a high school chemistry course influences learning of chemical phenomena. You are being invited to participate in this study because you are a student in a chemistry course where emphasis is placed on how particles can be used to explain observations of chemical events.

DESCRIPTION OF PROCEDURES

If you agree to participate in this study, your participation will last for second semester of the 2005-2006 school year. Participation means that your scores on various assessments may be used for analysis. The content of the course will in no way be altered by this study; all homework, quizzes, tests, lectures, laboratory activities and other classroom activities are designed to meet pre-determined learning objectives for the course.

RISKS

No foreseeable risks exist at this time from participation in the study.

BENEFITS

If you decide to participate in this study there may be no direct benefit to you. It is hoped that the information gained in this study will benefit society by providing a guide for future chemistry instruction with regard to the particulate nature of matter.

COSTS AND COMPENSATION

You will not be compensated for your participation in this research.

CONFIDENTIALITY

Records of participation in this research project will be maintained and kept confidential to the extent permitted by law and will not be released without your prior authorization unless ordered by a court of law. Identification numbers will be used to identify subjects in the study. In the event of any report or publication from this study, the identity of participants will not be disclosed.

VOLUNTARY PARTICIPATION

All participation is voluntary. No penalty exists to anyone who decides not to participate, nor will anyone be penalized if he or she decides to stop participation at any time during the research project.

QUESTIONS

We openly invite your questions and concerns. Please feel free to contact us at the numbers listed below if you have questions at any time.

Aileen Sullivan, Iowa State University, Ames, IA	*(515) 233-8563*
Dr. Joanne K. Olson, Iowa State University, Ames, IA	*(515) 294-3315*

If you have any questions about the rights of research subjects or research-related injury, please contact Ginny Austin Eason, IRB Administrator, (515) 294-4566, austingr@iastate.edu, or Diane Ament, Director, Office of Research Assurances (515) 294-3115, dament@iastate.edu.

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PARTICIPANT SIGNATURE

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the signed and dated written informed consent prior to your participation in the study.

Participant's Name (printed) ____

______________________________________ ______________________

Participant's Signature Date

______________________________________ ______________________

Signature of Parent/Guardian or Date
Legally Authorized Representative

INVESTIGATOR STATEMENT

I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

______________________________________ ______________________

Aileen M. Sullivan Date

Appendix B

Solution Unit Objectives, Particulate Nature of Matter Instruction, and Examples for Control and Treatment Groups

Table 5. Objectives, Particulate Instruction, and Examples

Objective	Particulate Nature of Matter Instruction	Control Group Examples	Treatment Group Examples
1. Define and apply the terms solute, solvent, and solution.	Instructor and students drew pictures of dissolving, both for ionic and molecular compounds. Students viewed animations of dissolving. Students viewed and discussed in class an overhead transparency illustrating dissolving.	Substances for "What is a Solution?" activity: pentane and water, 0.1 M nickel nitrate, sat. magnesium hydroxide, 0.1 M sodium fluoride, water with food coloring, 0.1 M copper (II) nitrate, sat. sodium chloride, distilled water, 0.1 M sodium bicarbonate, toluene and water, rheoscopic fluid, and sat. potassium nitrate	Substances for "What is a Solution?" activity: Kool-Aid, Orbitz ® pop, Italian salad dressing, clay in water, Diet Mt. Dew, Milk of Magnesia, skim milk, Coca-Cola, flip over fun toy, Fresca soda, effervescent cold relief in water, Dial liquid soap, Gatorade
2. Define and recognize solutions that are unsaturated, saturated, or supersaturated.	Terms were defined with respect to number of solute particles that have dissolved in the solvent, i.e. supersaturated is described as too many particles dissolved than should be at a given temperature.	Examples used in class: Saturated and unsaturated: NaCl and KNO_3 Supersaturated: reusable sodium acetate hand warmer	Examples used in class: Unsaturated: sugar in water Saturated: syrup Supersaturated: reusable sodium acetate hand warmer
3. Explain how the solubility of solids and gases dissolved in liquids changes with temperature. (Create and interpret solubility curves.)	Instructor and students drew pictures representing solid and gas particles dissolved in a solvent. The influence of temperature on dissolving was explained with respect to solvent and solute particles.	Examples used in class: Solid in liquid solubility: copper (II) sulfate color in hot and cold water Gas in liquid solubility: heating water on hot plate, beaker of water left out over time with bubbles	Examples used in class: Solid in liquid solubility: syrup making, tea bag in hot and cold water Gas in liquid solubility: cloudy hot water from a faucet, hot water vs. cold water to make ice cubes

Table 4. (continued)

Objective	Particulate Nature of Matter Instruction	Control Group Examples	Treatment Group Examples
3. (Create and interpret solubility curves.)		Pre-made transparency of solubility curves, gas and solid	Pre-made transparency of solubility curves, gas and solid
4. Calculate concentrations of solutions such as molarity (M), molality (m), mass percent (%), and parts per million (ppm). Calculate the concentration of solutions that have been diluted.	The different concentrations were discussed as the number of solute particles per volume or mass of solvent.	Examples used in class: Concentrated: pH buffer solution, Con. HCl Dilute: glass bottle with Dil HCl and HNO_3 labels Percent by mass: Indophenol, 0.1% Percent by volume: hydrogen peroxide, 30% Parts per million: Gibberillic Acid, 100 ppm For demo particle reflection: 4 bottles of the same size filled with colored liquid: isopropyl alcohol (red), vegetable oil (yellow), water (blue), and calcium chloride dissolved in water (green) (listed from least to most dense, two floaters and two sinkers)	Examples used in class: Concentrated: Orange Juice, Diet Mountain Dew, Wild Cherry Capri Sun Percent by mass: saline solution Percent by volume: Hydrogen peroxide, 3% Parts per million: water and chlorine For demo particle reflection: diet Coke, Diet Caffeine Free Pepsi, Coke and Cherry Coke (listed from least to most dense, two floaters and two sinkers)

Table 4. (continued)

5. Identify and apply factors that determine conductivity of solutions.	Used formulas and molarities to explain relative conductivity with respect to ions: more ions mean more conductivity.	Examples used in class: 1 M NaCl as compared to 1 M $CaCl_2$ and 1M $AlCl_3$ Which will conduct better? 2 M $FeBr_3$ or 3 M LiF ? Mainly a particle application.	Examples used in class: 1 M NaCl as compared to 1 M $CaCl_2$ and 1M $AlCl_3$ Which will conduct better? 2 M $FeBr_3$ or 3 M LiF ? Mainly a particle application.
6. Describe colligative properties and identify factors that influence these properties.	Described freezing and boiling with respect to speed and attractive forces between particles (an extension of a concept from earlier in the year).	Examples used in class: 1 mol of lauric acid has same influence as 1 mol glucose (same number of particles). It doesn't matter what the solute is, only that the more solute added the greater the effect. Demonstration: Ice water bath with thermometer, the temperature is measured before adding KNO_3. The temperature is monitored as an increasing amount of KNO_3 is added to the beaker. Laboratory Activity: A Study of Freezing Point Ethylene glycol was used as the solute as students made and measured the temperature change of different percent (by mass) solutions of ethylene glycol and ice.	Examples used in class: Why salt is used on icy roads and sidewalks and what effect this really has on the ice. Why is rock salt used on the ice in homemade ice cream? Demonstration: Ice water bath with thermometer, the temperature is measured before adding salt (NaCl). The temperature is monitored as an increasing amount of salt is added to the beaker. Laboratory Activity: A Study of Freezing Point Antifreeze was used as the solute as students made and measured the temperature change of different percent (by mass) solutions of antifreeze and ice.

Table 4. (continued)

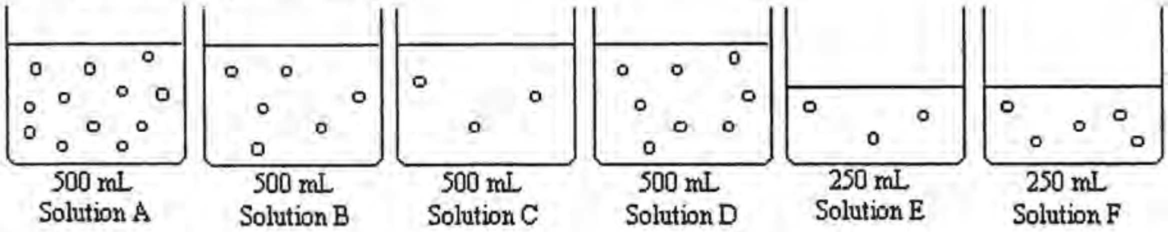
7. Calculate temperature changes associated with colligative properties.	Used the concept of the van't Hoff factor to calculate differences in temperature changes caused by ionic and molecular compounds of the same molality. More particles for the ions cause greater effect.	Examples used in class: A solution is prepared containing 50.0 mL of ethylene glycol (density 1.12 g/mL) in 50 grams of water. Calculate the freezing point of this 50/50 mixture. K_f of water is 1.86 °C/m and the formula for ethylene glycol is $C_2H_6O_2$. How many grams of citric acid, $C_6H_8O_7$, would have to be dissolved in 100.0 g cyclohexane to increase the boiling point by 2.0 °C ? The K_b of cyclohexane is 2.75 °C/m. Which will have the lowest freezing point? 1 M NaCl, 1 M $CaCl_2$, or 1 M $AlCl_3$	Examples used in class: A solution is prepared containing 50.0 mL of antifreeze (density 1.12 g/mL) in 50 grams of water. Calculate the freezing point of this 50/50 mixture. K_f of water is 1.86 °C/m and the formula for antifreeze is $C_2H_6O_2$. How many grams of salt, NaCl, would need to be added to 6 quarts of water (1 quart = 943 mL) to create a solution that boils at 105^{O}C? K_b of water is 0.512°C/m Which will be the most effective on icy roads in the winter? 1 M NaCl, 1 M $CaCl_2$, or 1 M $AlCl_3$

Appendix C

Quiz and Exam Assessments and Answers

C.1: Chemistry Solutions Quiz - Answers included

1. The drawings below represent beakers of aqueous solutions. Each o represents a dissolved solute particle. (2 points each)



a. Rank the solutions above from least concentrated to most concentrated.
   C < B = E < D < F < A

b. When Solutions E and F are combined, the resulting solution has the same concentration as Solution D.

c. If you evaporate off half of the water in Solution B, the resulting solution has the same concentration as Solution A.

d. If you place half of Solution A in another beaker and then add 250 mL of water, the resulting solution has the same concentration as Solution B OR E.

2. It is a hot summer day and you have just finished mowing your neighbor, Sophie's, lawn. As a treat for you, she pours a tall, cold glass of lemon-lime Kool-Aid. Yummy! You decide to teach Sophie a little chemistry. How would you show her if the Kool-Aid is unsaturated, saturated, or super-saturated? (3 points)

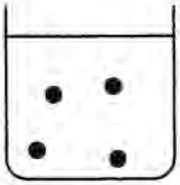
2 points: add more sugar and/or Kool-Aid ® mix.
1 point: Unsaturated, when more is added the additional substance(s) will dissolve.
Saturated, when more is added the additional substance(s) will not dissolve.
Supersaturated, when more is added more than the additional substance(s) will crystallize out of the solution.

3. Describe what happens when KBr is placed in water. Use pictures if they would be helpful in your description. (3 points)

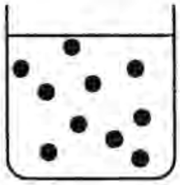
1 point: The KBr splits into ions.
1 point: The KBr is pulled apart by water molecules.
1 point: The KBr dissolves, forms a solution, or acts as a solute.

C.1 (continued)

4. Carbonated water is the product of carbon dioxide gas dissolved in water. How is the solubility of carbon dioxide gas influenced by temperature? Use the beakers below to illustrate the dissolved molecules of carbon dioxide in hot and cold water. (3 points)



Hot Water
1 point



Cold Water
1 point

1 point: A gas will decrease in solubility with an increase in temperature.

5. Rank the following solutions in order of increasing conductivity. 0.1 M CaF_2, 0.1 M LiF, and 0.2 M LiF Explain your ranking. (4 points)

0.1 M LiF < 0.1 M CaF_2 < 0.2 M LiF

As the number of ions increases the ability to conduct electricity increases.

C.2: Third Quarter Exam Multiple Choice - Answers underlined

1. The bonding in BaF_2 is classified as
   a. ionic. b. covalent. c. metallic. d. nonpolar.

2. A chemical system has reached equilibrium when the
   a. forward reaction ceases.
   b. concentrations of the reactants and products become constant
   c. reverse reaction begins
   d. concentrations of the reactants and products become equal.

3. A change in one of the conditions, such as temperature or pressure, that effects an equilibrium system is called
   a. a shift. b. a stress. c. reversibility. d. displacement.

4. The phrase "like dissolves like" is frequently used in describing solutions. What is "like"?
   a. their densities c. their heats of formation
   b. their masses d. their molecular polarities

5. A reaction that produces a large quantity of products before reaching equilibrium is recognized by an equilibrium constant that is:
   a. a large number c. a negative number
   b. a small number d. zero

6. Water is known as the "universal solvent" because it dissolves many things. The dissolving power of water is mainly due to its:
   a. ionic bonds c. polar covalent bonds
   b. covalent bonds d. molecule polarity

7. The bonds in PCl_3 are best described as
   a. ionic b. non-polar covalent c. polar covalent

8. Which solution contains the same total number of ions per liter as 1.0 M $FeCl_2$?
   a. 1.0 M $AlCl_3$ c. 0.5 M $CuSO_4$
   b. 2.0 M NaCl d. 1.5 M KBr

9. What happens to the molarity when 250 mL of a 3.0 M solution is diluted to 1 liter?
   a. molarity increases
   b. molarity remains constant
   c. molarity decreases

10. The *amount* of a substance that can dissolve in another substance is affected by all of the following except
    a. the nature of the substances. c. the pressure.
    b. the temperature. d. stirring.

C.2 (continued)

11. A 1.0 M solution of sugar in water is prepared and divided into two equal volumes, A and B. More sugar is added to volume A and more water is added to volume B. Which of the following statements is correct?

a. A is more concentrated than B c. A is less saturated than B
b. A is more dilute than B d. A and B have the same molarity

12. Which best describes the relationship between ions and conductivity?

a. More ions in a solution will result in greater conductivity.
b. More ions in a solution will result in less conductivity.
c. There is no relationship between ions and conductivity.

13. A saturated solution of potassium nitrate (KNO_3) may be made unsaturated by:

a. raising its temperature. c. adding more solute.
b. raising the pressure. d. stirring vigorously.

14. How many moles of potassium hydroxide, KOH, are needed to prepare 2 L of a 2 M solution?

a. 1 mole b. 2 moles c. 3 moles d. 4 moles

15. A small crystal of the slightly soluble salt calcium sulfate ($CaSO_4$) dissolves in a water solution of calcium sulfate. The original solution must have been:

a. unsaturated. b. saturated. c. supersaturated. d. not enough information

16. When substances are dissolved in water the effect is to

a. raise the boiling point and lower the freezing point of the water.
b. raise both the boiling point and freezing point of the water.
c. lower both the boiling point and freezing point of the water.
d. lower the boiling point and raise the freezing point of the water.

17. At which temperature will water, in an open container, dissolve the greatest amount of oxygen? a. 1 °C b. 4 °C c. 32 °C d. 100 °C

18. What mass of sodium chloride remains when 250 mL of a 0.200 M solution of sodium chloride is carefully evaporated to dryness?

a. 2.93 g b. 11.7 g c. 14.6 g d. 58.5 g

19. Four different solutions were prepared by dissolving 0.1 mol of each of these materials in one liter of water. Which solution has the lowest freezing point?

a. K_2SO_4 b. NaOH c. Na_3PO_4 d. HCl

20. If 50 mL of a 200 mL sample of 0.10 M sodium chloride solution is spilled, what is the concentration of the remaining solution?

a. 0.20 M b. 0.10 M c. 0.075 M d. 0.025 M

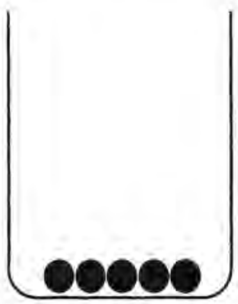
C.3: Third Quarter Exam Free Response - Answers included

SHORT ANSWER/ PROBLEM SOLVING *Include any and all information you think necessary to answer the following using complete sentences.*

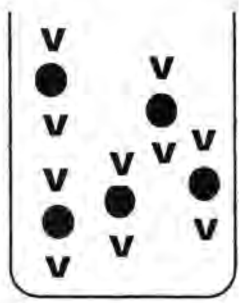
21. Antifreeze, a polar liquid also known as ethylene glycol, is a common additive to the water in car engine radiators in the wintertime here in Ames. Antifreeze can also be added to engines during the summer months. Explain why antifreeze would be a beneficial additive in both winter and summer. (4 points)

1 point: Some kind of answer related to solutions.
1 point: Antifreeze is a solute or a solution is made.
1 point: Raises the boiling point.
1 point: Lowers the freezing point.

22. The beaker below represents 5 molecules that are able to dissolve in water. The molecules are represented by the solid circles. Draw a new beaker that represents the molecules dissolved in water. Provide a brief explanation for your new drawing. (4 points)



1 point: Some kind of answer related to solutions.
1 point: Water attracts molecules and pulls them apart from each other (not into ions.)
1 point: Each molecule is surrounded by molecules of water.
1 point: Water "poles" switched around.



Problem Solving *Show all work to earn partial credit for the following problems.*

23. What is the freezing point of a solution with 50 g of $MgSO_4$ dissolved in 100 g of water? K_f of water is 1.86 °C/*m* (4 points)

(50 g $MgSO_4$)(1 mol/120 g) = 0.42 mol

$\Delta T_f = K_f m$
$\Delta T_f =$ (1.86 °C/m)(0.42 mol/0.1 kg)(2 ions)
$\Delta T_f =$ 15.6 °C

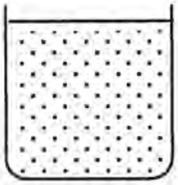
1 point: Tried to solve the problem
1 point: Correct molality
1 point: Recognize 2 ions
1 point: Subtract answer from 0 °C

Freezing point = 0 °C – 15.6 °C = - 15.6 °C

C.3 (continued)

24. How much water would have to be added to 500 mL of 18.0 M H_2SO_4 solution in order to bring its concentration down to 3.0 M? The beaker on the left below represents the initial solution. Draw and label a beaker to represent the new solution. (4 points)

500 mL of 18.0 M H_2SO_4



3000 mL of 3.0 M H_2SO_4

M = mol/L
18 M = x/0.5 L
x = 9 mol

3 M = 9 mol/x
x = 3 L

3 L – 0.5 L = 2.5 L of water

1 point: Tried to solve the problem
1 point: Representation of new solution
1 point: Calculated 3 L.
1 point: Subtracted original 0.5 L from 3 L of new solution.

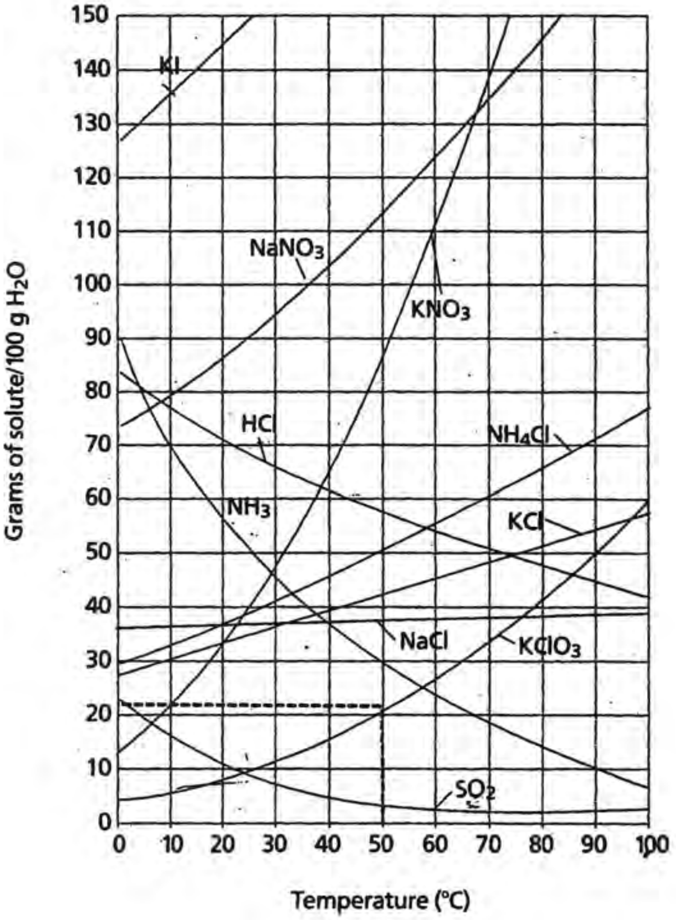
25. The following equation represents one of the equilibrium systems in a bottle of carbonated beverage: $H_2CO_3\ (aq) \Leftrightarrow H_2O\ (l) + CO_2\ (g)$
Indicate how the equilibrium would be affected by the following changes (direction of shift). (2 points each) 1 point for an answer, 1 point for the correct answer.

a. Opening the top of the bottle.	Right
b. Diluting the soda with water.	Left
c. Warming the bottle.	Right
d. Increasing the pressure in the bottle by pumping in more CO_2.	Left

26. *Refer to the solubility curve to answer the following:* (1 point each) 1 point for correct answer, 0 points for incorrect answer.

a. How much KCl is required to create a saturated solution in 100 g of water at 50°C?	42 g
b. How much KNO_3 would be needed to create a saturated solution in 500 g of water at 10°C?	110 g
c. If 30 grams of NaCl were stirred into 100 g of water at 80°C, would the solution be unsaturated, saturated or supersaturated?	Unsaturated
d. If 60 grams of NaCl were stirred into 200 g of water at 80°C, would the solution be unsaturated, saturated or supersaturated?	Unsaturated
e. How much solute would crystallize (come out of solution) if saturated $KClO_3$ in 100 g of water was cooled from 50°C to 10°C?	14 g

Solubility Curves for Selected Solutes



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